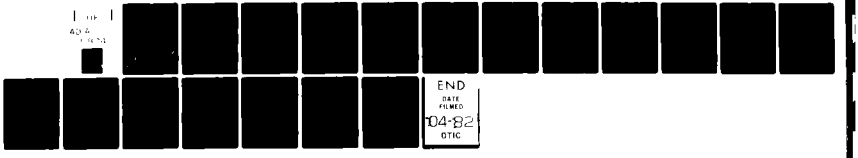
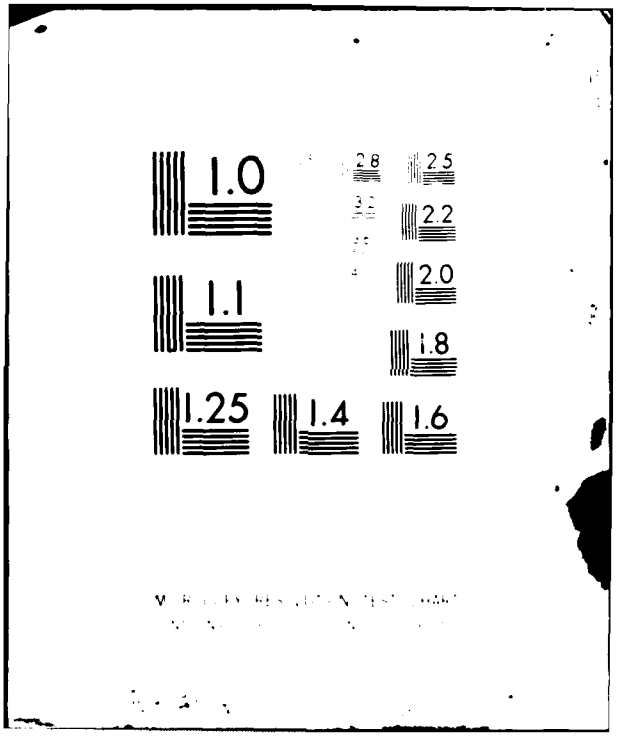
AD-A111 874 NAVAL SURFACE WEAPONS CENTER SILVER SPRING MD F/G 20/7
GRAD-B DRIFT OF AN ELECTRON BEAM IN THE HIGH CURRENT BETATRON.(U)
SEP 81 H S UHM
UNCLASSIFIED NSWC/TR-81-383 SBI-AD-F500 001 NL



END
DATE FILMED
04-82
DTIC


1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

AP-F500001

(12)

NSWC TR 81-383

# GRAD-B DRIFT OF AN ELECTRON BEAM IN THE HIGH CURRENT BETATRON

BY HANS S. UHM

RESEARCH AND TECHNOLOGY DEPT.

SEPTEMBER 1981

Approved for public release, distribution unlimited

AD A111874

DTIC FILE COPY

MAR 1 1 1982

D

A

NAVAL SURFACE WEAPONS CENTER

Dahlgren, Virginia 22448 • Silver Spring, Maryland 20910

82 02 22 036

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>NSWC TR 81-383 | 2. GOVT ACCESSION NO.<br>AD-A111 874 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>Grad-B Drift of an Electron Beam in the High Current Betatron | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final<br>6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>Dr. Han S. Uhm | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Naval Surface Weapons Center<br>White Oak, Silver Spring, Maryland 20910<br>(R41) | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>61152N, ZR00001,<br>ZR01109, 0 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS | | 12. REPORT DATE<br>September 1981<br>13. NUMBER OF PAGES<br>20 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED<br>15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

High Current Betatron, Electron Beam, Grad-B Drift, Accelerator

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The equation of motion of the center of mass coordinates for an electron beam in the high current betatron is investigated. For a small betatron field, it is shown that even for a stable single particle orbit of beam electrons, the grad-B drift velocity of the center of mass coordinates can be fractional percents of the speed of light, thereby presenting a serious difficulty in future experiments.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

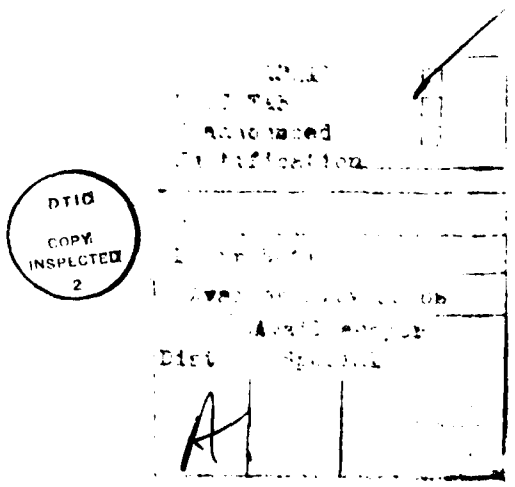
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# FOREWORD

The equation of motion of the center of mass coordinates for an electron beam in the high current betatron is investigated. For a small betatron field, it is shown that even for a stable single particle orbit of beam electrons, the grad-B drift velocity of the center of mass coordinates can be fractional percents of the speed of light, thereby presenting a serious difficulty in future experiments.

Ira M Blatstein

IRA M. BLATSTEIN
By direction



CONTENTS


| | Page |
|---|---|
| INTRODUCTION | 5 |
| SINGLE PARTICLE ORBIT IN EQUILIBRIUM STATE WITH (X,Z) = (0,0) | 7 |
| CENTER OF MASS ORBIT | 8 |
| GRAD-B DRIFT MOTION WITH SMALL BETATRON FIELD | 10 |
| REFERENCES | 15 |


ILLUSTRATION


| Figure | | Page |
|---|---|---|
| 1 | CONFIGURATION AND COORDINATE SYSTEM. (a) OVERVIEW AND (b) CROSS SECTION OF THE MINOR DIMENSION | 12 |

## INTRODUCTION

In recent years, there have been numerous investigations in the high current betatron accelerators,[1-3] in connection with generations of intense high energy electron beams. In a conventional betatron accelerator, a toroidal configuration of electrons is confined in a betatron (or mirror) magnetic field. As shown in Fig. 1a, in the present high current betatron accelerator,[1,2] an additional focussing magnetic field in the azimuthal direction is applied, thereby considerably enhancing the current limitation. However, in the present article, we investigate the equation of motion of the center of mass coordinates for electron beam, with particular emphasis on the grad-B drift[4] caused by the variation of the azimuthal magnetic field with the radial coordinate r.

As shown in Fig. 1a, the equilibrium configuration consists of a relativistic electron ring located at the midplane of externally imposed mirror field $B_{er}(r,z)\hat{e}_r + B_{ez}(r,z)\hat{e}_z$. In addition, the applied azimuthal magnetic field $B_{e\theta}\hat{e}_\theta$ with the mirror field acts to confine the ring both axially and radially. Here, $\hat{e}_r$, $\hat{e}_\theta$, and $\hat{e}_z$ are the unit vectors along the cylindrical coordinates r, $\theta$, and z, respectively. The equilibrium radius of the ring is denoted by $R_0$, and the minor dimensions of the ring is denoted by 2a (radial direction) and 2b (axial direction). The minor dimensions of the ring are much smaller than its major radius $R_0$. The electron composing the ring gyrate in the external mirror field with azimuthal velocity $\beta_b c = (\gamma_b^2 - 1)^{1/2} c/\gamma_b$ in the positive $\theta$-direction. The associated ring current produces a self magnetic field $B_s(x)$, which tends to compress the minor dimensions of the ring both axially and radially. The electron ring is assumed to be partially neutralized by a positive ion

background with a fractional charge neutralization f. The excess electrons forms the electrostatic field which tends to increase the minor dimensions of the ring.

For the convenience of future analysis, we define $x = r - R_0$. Shown in Fig. 1b is the configuration and coordinate system of the minor dimension. The center of mass coordinates of electron beam are denoted by (X,Z). The electron density profile is assumed to be

$$n_b^0(x,z) = n_b U[1 - (x - X)^2/a^2 - (z - Z)^2/b^2] , \qquad (1)$$

where U(x) is the Heaviside step function and $n_b$ is the electron density at the center of mass coordinates (X,Z). The self electric and magnetic fields produced by beam itself exert the transverse force[5,6]

$$\underset{\sim}{F}_s = -\gamma_b m[\omega_r^{s2}(x - X)\hat{\underset{\sim}{e}}_r + \omega_z^{s2}(z - Z)\hat{\underset{\sim}{e}}_z] , \qquad (2)$$

on the beam electrons. Here $\omega_r^{s2}$ and $\omega_z^{s2}$ are the radial and axial betatron frequency-squareds of the self field defined by

$$\omega_r^{s2} = \frac{b}{a+b}\omega_p^2[\beta_b^2 - (1 - f)] ,$$

$$\omega_z^{s2} = \frac{a}{a+b}\omega_p^2[\beta_b^2 - (1 - f)] , \qquad (3)$$

and $\omega_p^2 = 4\pi n_b e^2/\gamma_b m$ is the plasma frequency-squared for beam electrons.

From $(\nabla \times \underset{\sim}{B})_z = 0$, we obtain $\partial B_{e\theta}/\partial r = -B_{e\theta}/r$ and the symmetry about the z = 0 plane implies $(\partial B_{e\theta}/\partial z)_0 = 0$. Thus, $B_{e\theta}(r,z)$ is approximated by

$$B_{e\theta}(r,z) \simeq B_{e\theta}(R_0,0)(1 - x/R_0) . \qquad (4)$$

Making use of Eqs. (3) and (4), one can obtain the transverse equations of motion

$$\ddot{x} + \omega_c^2(1 - n)x + \omega_r^{s2}(x - X) = \omega_\theta(1 - x/R_0)\dot{z} ,$$

$$\ddot{z} + \omega_c^2 nz + \omega_z^{s2}(z - Z) = -\omega_\theta(1 - x/R_0)\dot{x} , \qquad (5)$$

for beam electrons. In Eq. (5), $n = -[R_0/B_{ez}(R_0,0)][(\partial/\partial r)B_{ez}(r,0)]_{R_0}$ is the external field index of the mirror field, dot ($\cdot$) denotes the time derivative d/dt, and $\omega_c = eB_{ez}(R_0,0)/\gamma_b mc$ and $\omega_\theta = eB_{e\theta}(R_0,0)/\gamma_b mc$ are the electron cyclotron frequencies of the axial and azimuthal magnetic fields, respectively. Note that in Eq. (5), the terms proportional to $x/R_0$ are contributed by the variation of the azimuthal magnetic field with r.

SINGLE PARTICLE ORBIT IN EQUILIBRIUM STATE WITH (X,Z) = (0,0)

In this case, Eq. (5) can be simplified by

$$\ddot{x} + \omega_r^2 x - \omega_\theta \dot{z} = 0 ,$$

$$\ddot{z} + \omega_z^2 z + \omega_\theta \dot{x} = 0 , \qquad (6)$$

where $\omega_r^2 = \omega_c^2(1 - n) + \omega_r^{s2}$ and $\omega_z^2 = \omega_c^2 n + \omega_z^{s2}$ are the radial and axial betatron frequency-squareds for external and self fields. In obtaining Eq. (6), use has been made of the fact that $|\omega_r^2| \approx |\omega_z^2| \approx \omega_\theta^2$ for a high current betatron. With the usual assumption that x and z have solutions of the sinusoidal form

$$x = c\sin(\omega t + \alpha),\ z = d\cos(\omega t + \alpha) , \qquad (7)$$

it can be shown that Eq. (6) reduces to

$$d/c = (\omega^2 - \omega_r^2)/\omega\omega_\theta , \qquad (8)$$

and the dispersion relation

$$(\omega^2 - \omega_r^2)(\omega^2 - \omega_z^2) = \omega_\theta^2\omega^2 \ , \tag{9}$$

which gives the eigenfrequencies $\omega = \omega_b^{\pm}$ defined by

$$2(\omega_b^{\pm})^2 = \omega_r^2 + \omega_z^2 + \omega_\theta^2 \pm [(\omega_r^2 + \omega_z^2 + \omega_\theta^2)^2 - 4\omega_r^2\omega_z^2]^{1/2}, \tag{10}$$

where the two sign (±) represent fast (+) and slow (-) oscillation states. The necessary and sufficient condition for stable single particle orbit is given by

$$(\omega_r^2 + \omega_z^2 + \omega_\theta^2) > 2|\omega_r\omega_z|, \ \omega_r^2\omega_z^2 > 0, \tag{11}$$

which is identical to the previous result[7] obtained for the plasma betatron.

CENTER OF MASS ORBIT. Neglecting momentum spread, Eq. (5) can be averaged over the beam cross section. After some straightforward algebra, we obtain the transverse equation of motion for the center of mass coordinates

$$\begin{aligned} \ddot{X} + \omega_c^2(1 - n)X &= \omega_\theta[\dot{Z} - (X\dot{Z} - \omega_\theta a^2\eta/2)/R_0] \ , \\ \ddot{Z} + \omega_c^2 nZ &= -\omega_\theta[\dot{X} - X(\dot{X} - \omega_\theta b\zeta)/R_0] \ , \end{aligned} \tag{12}$$

where $\eta$ and $\zeta$ are the form factors of the nonlinear terms with order unity. However, these form factors depend on the oscillation state of individual electron motions.

As a simple example, we consider the fast oscillation state for single particle electron orbit. That is

$$x = X + c\sin(\omega_b^{+}t + \alpha), \ z = Z + d\cos(\omega_b^{+}t + \alpha) \ . \tag{13}$$

Thus, after a straightforward algebraic manipulation, we obtain

$$\langle x\dot{z}\rangle = X\dot{Z} + a^2(\omega_r^2 - \omega_b^{+2})/4\omega_\theta \ , \tag{14}$$

where the bracket <> represents the average over the beam cross section. From Eq. (14), we identify,

$$\eta = (\omega_b^{+2} - \omega_r^2)/2\omega_\theta^2 \ . \tag{15}$$

Similarly, the form factor $\zeta$ is given by

$$\zeta = 4(\omega_b^{+2} - \omega_z^2)/3\pi\omega_\theta^2 \ , \tag{16}$$

for the fast oscillation state corresponding to Eq. (13). In reality, the single particle electron orbit is the linear combination of the fast and slow oscillation states, thereby considerably complicating the form factor determination.

When the betatron field is sufficiently large, satisfying the ratio $\rho = \omega_c^2 R_0/a\omega_\theta^2 >> 1$, then Eq. (12) can be simplified by

$$\begin{aligned} \ddot{X} + \omega_c^2(1 - n)X &= \omega_\theta \dot{Z} \ , \\ \ddot{Z} + \omega_c^2 nZ &= -\omega_\theta \dot{X} \ , \end{aligned} \tag{17}$$

which is an identical form to Eq. (6). Assuming that $X = \xi_x \sin(\Omega t + \alpha)$ and $Z = \xi_z \cos(\Omega t + \alpha)$, one can show that the general solution is the linear combination of the fast (+) and slow (-) oscillation states with the eigenfrequency $\Omega = \Omega_b^{\pm}$ defined by $2(\Omega_b^{\pm})^2 = \omega_c^2 + \omega_\theta^2 \pm [(\omega_c^2 + \omega_\theta^2)^2 - 4n(1 - n)\omega_c^4]^{1/2}$. The center of mass orbit can then be expressed as

$$X^2 + \Omega^2\{\omega_\theta/[\Omega^2 - (1-n)\omega_c^2]\}^2 Z^2 = \xi_r^2 \ , \tag{18}$$

for either fast or slow oscillation state. In this regard, we note from Eq. (18) that the center of mass orbit for the slow oscillation

state is hyperbolic [$n(1 - n) < 0$] or elliptic [$n(1 - n) > 0$], depending on the external field index.

GRAD-B DRIFT MOTION WITH SMALL BETATRON FIELD. When the betatron field is small, so that the betatron focussing terms are less than the nonlinear $B_{e\theta}$ terms (i.e., $\rho << 1$), then Eq. (12) can be approximated by

$$\ddot{X} - \omega_\theta \dot{Z} = -\omega_\theta (X\dot{Z} - \omega_\theta a^2 n/2)/R_0 ,$$

$$\ddot{Z} + \omega_\theta \dot{X} = \omega_\theta X(\dot{X} - \omega_\theta b\zeta)/R_0 . \tag{19}$$

Equation (19) has been previously investigated by Ferrari and Zucker[8] for the single particle orbit calculation in the plasma betatron. The result is given by

$$X = X_0 + \xi_x \sin(\omega_\theta t + \alpha) + \ldots$$

$$Z = Z_0 + \xi_x \cos(\omega_\theta t + \alpha) + v_g t + \ldots , \tag{20}$$

where $X_0$ and $Z_0$ are constants determined from the initial values, the symbol (...) represents the higher order oscillation terms and

$$v_g = -\omega_\theta (\xi_x^2 + a^2 n)/2R_0 , \tag{21}$$

is the grad-B drift velocity in the z-direction.

Even though the single particle orbit of beam electrons in a high current beam is stable [see Eq. (11)], the center of mass coordinates exhibits a drift motion for a small betatron field. As shown in Eq. (21), the grad-B drift velocity can be fractional percents of the speed of light in the present experimental parameters of a high current betatron. However, in the time varying betatron field, the external focussing terms [terms proportional to $\omega_c^2$ in Eq. (12)]

together with this grad-B drift motion give a finite displacement[8] of the center of mass coordinates (X,Z) from their equilibrium values (0,0). In this regard, it is required to determine an appropriate time profile for the betatron field, thereby reasonably confining an electron beam near its equilibrium orbit.

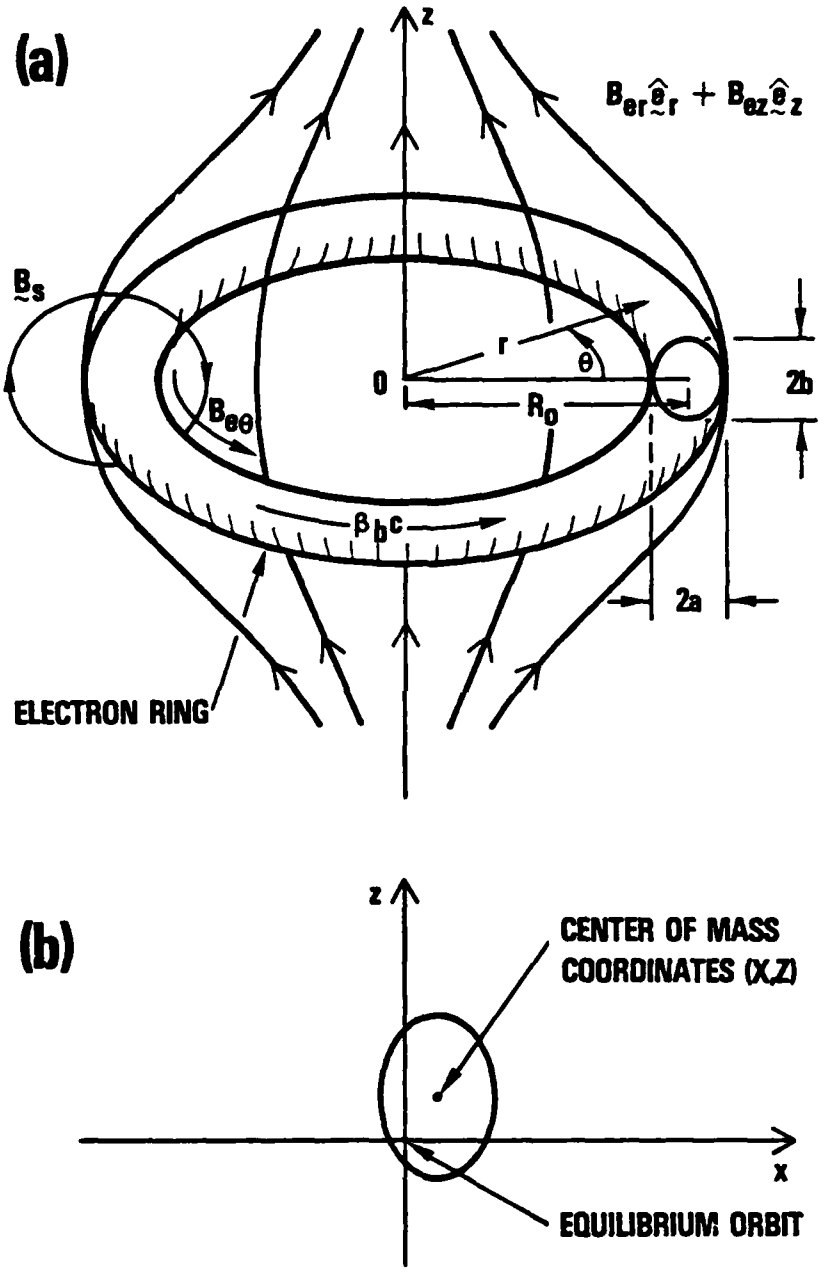



FIGURE 1 CONFIGURATION AND COORDINATE SYSTEM.
(a) OVERVIEW AND (b) CROSS SECTION OF THE MINOR DIMENSION.

ACKNOWLEDGMENT

It is a pleasure to acknowledge the benefit of useful discussions with Drs. Won Namkung and C. A. Kapetanakos. This research was supported by the Independent Research Fund at Naval Surface Weapons Center and by the Department of Defense Advanced Research Projects Agency.

REFERENCES

1. P. Sprangle and C. A. Kapetanakos, J. Appl. Phys. 49, 1 (1978).

2. G. Barak, A. Fisher, and H. Ishizuka, and N. Rostoker, IEEE Trans. NS-28, 3340 (1981).

3. A. Fisher, P. Gilad, F. Goldin, and N. Rostoker, Appl. Phys. Lett. 36, 264 (1980).

4. T. J. M. Boyd and J. J. Sanderson, Plasma Dynamics (Barnes & Noble, Inc., New York 1969), Ch. 2.

5. R. C. Davidson and J. D. Lawson, Part. Accel. 4, 1 (1972).

6. H. S. Uhm, Ph.D. Thesis, Univ. of Maryland (1976).

7. L. A. Ferrari and M. S. Zucker, Phys. Fluids 12, 1312 (1969).

8. L. A. Ferrari and M. S. Zucker, Part. Accel. 2, 121 (1971).

DISTRIBUTION

| | Copies |
|---|---|
| Commander | |
| Naval Research Laboratory | |
| Attn: Dr. Saeyoung Ahn | 1 |
| Dr. Wahab A. Ali | 1 |
| Dr. J. M. Baird | 1 |
| Dr. L. Barnett | 1 |
| Dr. O. Book | 1 |
| Dr. Jay Boris | 1 |
| Dr. K. R. Chu | 1 |
| Dr. Timothy Coffey | 1 |
| Dr. G. Cooperstein | 1 |
| Dr. A. Drobot | 1 |
| Dr. Richard Fernslor | 1 |
| Dr. H. Freund | 1 |
| Dr. M. Friedman | 1 |
| Dr. J. Golden | 1 |
| Dr. S. Goldstein | 1 |
| Dr. V. Granatstein | 1 |
| Dr. Robert Greig | 1 |
| Dr. Irving Haber | 1 |
| Dr. Richard Hubbard | 1 |
| Dr. Bertram Hui | 1 |
| Dr. Glenn Joyce | 1 |
| Dr. Selig Kainer | 1 |
| Dr. C. A. Kapetanakos | 1 |
| Dr. M. Lampe | 1 |
| Dr. Y. Y. Lau | 1 |
| Dr. W. M. Manheimer | 1 |
| Dr. Don Murphy | 1 |
| Dr. Peter Palmadesso | 1 |
| Dr. Robert Pechacek | 1 |
| Dr. Michael Picone | 1 |
| Dr. Michael Raleigh | 1 |
| Dr. M. E. Read | 1 |
| Dr. C. W. Roberson | 1 |
| Dr. J. D. Sethian | 1 |
| Dr. William Sharp | 1 |
| Dr. J. S. Silverstein | 1 |
| Dr. Philip Sprangle | 1 |
| Dr. Doug Strickland | 1 |
| Dr. C. M. Tang | 1 |
| Dr. N. Vanderplaats | 1 |
| Washington, DC 20375 | |

| | Copies |
|---|---|
| Office of Naval Research | |
| Attn: Dr. Robert Behringer | 1 |
| 1030 E. Green | |
| Pasadena, CA 91106 | |
| | |
| Office of Naval Research | |
| Attn: Dr. T. Berlincourt | 1 |
| Dr. W. J. Condell | 1 |
| Department of the Navy | |
| Arlington, VA 22217 | |
| | |
| Commander | |
| Naval Air Systems Command | |
| Attn: Dr. Wasneski | 1 |
| Department of the Navy | |
| Washington, DC 20361 | |
| | |
| Commander | |
| Naval Sea Systems Command | |
| Attn: Dr. C. F. Sharn | 1 |
| Department of the Navy | |
| Washington, DC 20362 | |
| | |
| Harry Diamond Laboratory | |
| Attn: Dr. H. E. Brandt | 1 |
| Dr. S. Graybill | 1 |
| 2800 Powder Mill Road | |
| Adelphi, MD 20783 | |
| | |
| U. S. Army Ballistic Research Laboratory | |
| Attn: Dr. D. Eccleshall | 1 |
| Aberdeen Proving Ground | |
| MD 21005 | |
| | |
| Air Force Weapons Laboratory | |
| Attn: Dr. Ray Lemke | 1 |
| Kirtland Air Force Base | |
| Albuquerque, NM 87117 | |
| | |
| Air Force Weapons Laboratory | |
| Attn: Dr. D. Straw | 1 |
| Kirtland AFB, NM 87117 | |

DISTRIBUTION (Cont.)

| | Copies |
|---|---|
| U.S. Department of Energy | |
| Attn: Dr. T. Godlove | 1 |
| Dr. M. Month | 1 |
| Dr. J. A. Snow | 1 |
| Washington, DC 20545 | |
| National Bureau of Standards | |
| Attn: Dr. Sam Penner | 1 |
| Bldg. 245 | |
| Washington, DC 20234 | |
| National Bureau of Standards | |
| Attn: Dr. Mark Wilson | 1 |
| Gaithersburg, MD 20760 | |
| Defense Advanced Research Projects Agency | |
| Attn: Dr. J. Bayless | 1 |
| Dr. Robert Fossum | 1 |
| Dr. J. A. Mangano | 1 |
| LCOL W. Whitaker | 1 |
| 1400 Wilson Blvd. | |
| Arlington, VA 22209 | |
| Science Applications Inc. | |
| Attn: Dr. Richard E. Aamodt | 1 |
| 934 Pearl St. Suite A | |
| Boulder, CO 80302 | |
| Science Applications Inc. | |
| Attn: Dr. L. Feinstein | 1 |
| Dr. Robert Johnston | 1 |
| Dr. Douglas Keeley | 1 |
| Dr. John Siambis | 1 |
| 5 Palo Alto Square | |
| Palo Alto, CA 94304 | |
| Science Applications, Inc. | |
| Attn: Dr. A. W. Trivelpiece | 1 |
| San Diego, CA 92123 | |
| Science Applications, Inc. | |
| Attn: Dr. Ron Parkinson | 1 |
| 1200 Prospect Street | |
| P.O. Box 2351 | |
| La Jolla, CA 92038 | |

| | Copies |
|---|---|
| TRW | |
| Defense and Space Systems Group | |
| Attn: Dr. D. Arnush | 1 |
| Dr. M. Caponi | 1 |
| 1 Space Park | |
| Redondo Beach, CA 90278 | |
| Lawrence Livermore National Laboratory | |
| Attn: Dr. W. A. Barletta | 1 |
| Dr. R. Briggs | 1 |
| Dr. H. L. Buchanan | 1 |
| Dr. Frank Chambers | 1 |
| Dr. T. Fessenden | 1 |
| Dr. Edward P. Lee | 1 |
| Dr. James Mark | 1 |
| Dr. Jon A. Masamitsu | 1 |
| Dr. V. Kelvin Neil | 1 |
| Dr. R. Post | 1 |
| Dr. D. S. Prono | 1 |
| Dr. M. E. Rensink | 1 |
| Dr. Simon S. Yu | 1 |
| University of California | |
| Livermore, CA 94550 | |
| Physics International Co. | |
| Attn: Dr. Jim Benford | 1 |
| Dr. S. Putnam | 1 |
| 2700 Merced Street | |
| San Leandro, CA 94577 | |
| Sandia Laboratories | |
| Attn: Dr. K. D. Bergeron | 1 |
| Dr. B. Epstein | 1 |
| Dr. S. Humphries | 1 |
| Dr. Tom Lockner | 1 |
| Dr. Bruce R. Miller | 1 |
| Dr. C. L. Olson | 1 |
| Dr. Gerold Yonas | 1 |
| Albuquerque, NM 87115 | |
| La Jolla Institute | |
| Attn: Dr. K. Brueckner | 1 |
| Prof. N. M. Kroll | 1 |
| P.O. Box 1434 | |
| La Jolla, CA 92038 | |

DISTRIBUTION (Cont.)

| | Copies |
|---|---|
| Mission Research Corp. | |
| Attn: Dr. Neal Carron | 1 |
| Dr. Conrad Longmire | 1 |
| 735 State Street | |
| Santa Barbara, CA 93102 | |
| Mission Research Corp. | |
| Attn: Dr. B. Godfrey | 1 |
| 1400 San Mateo Blvd, S.E. | |
| Suite A | |
| Albuquerque, NM 87108 | |
| McDonnell Douglas Corp. | |
| Attn: Dr. M. Greenspan | 1 |
| Dr. J. Carl Leader | 1 |
| P. O. Box 516 | |
| St. Louis, MO 63166 | |
| Los Alamos National Lab. | |
| Attn: Dr. Barry Newberger | 1 |
| Dr. L. E. Thode | 1 |
| Mail Stop 608 | |
| Los Alamos, NM 87544 | |
| Los Alamos Scientific Lab. | |
| Attn: Dr. H. Dreicer | 1 |
| Dr. R. J. Faehl | 1 |
| Los Alamos, NM 87544 | |
| Pulse Sciences, Inc. | |
| Attn: Dr. Sid Putnam | 1 |
| 1615 Broadway, Suite 610 | |
| Oakland, CA 94612 | |
| National Science Foundation | |
| Attn: Dr. R. Hill | |
| Physics Division, #341 | |
| Washington, DC 20550 | |
| W. J. Schafer Associates, Inc. | |
| Attn: Dr. Edward Cornet | 1 |
| 1901 North Fort Myer Dr. | |
| Arlington, VA 22209 | |

| | Copies |
|---|---|
| Austin Research Associates | |
| Attn: Prof. W. E. Drummond | 1 |
| Dr. M. Lee Sloan | 1 |
| Dr. James R. Thompson | 1 |
| 1901 Rutland Drive | |
| Austin, TX 78758 | |
| Western Research Corporation | |
| Attn: Dr. Franklin Felber | 1 |
| 8616 Commerce Avenue | |
| San Diego, CA 92121 | |
| Jaycor | |
| Attn: Dr. J. U. Guillory | 1 |
| Dr. D. Tidman | 1 |
| 205 S. Whiting Street | |
| Alexandria, VA 22304 | |
| Varian Associates | |
| Attn: Dr. Howard Jory | 1 |
| 611 Hansen Way | |
| Palo Alto, CA 94303 | |
| Lawrence Berkeley Lab. | |
| Attn: Dr. Denis Keefe | 1 |
| Dr. Hogil Kim | 1 |
| Dr. Hong Chul Kim | 1 |
| Dr. Kwang Je Kim | 1 |
| Dr. L. J. Laslett | 1 |
| Dr. G. R. Lambertson | 1 |
| Dr. A. M. Sessler | 1 |
| Dr. L. Smith | 1 |
| 1 Cyclotron Road | |
| Berkeley, CA 94720 | |
| Stanford Linear Accelerator Center | |
| Attn: Dr. Philip Morton | 1 |
| P.O. Box 4349 | |
| Stanford, CA 94305 | |
| AVCO - Everett Research Laboratory, Inc. | |
| Attn: Dr. Richard Patrick | 1 |
| 2385 Revere Beach Pkwy | |
| Everett, MA 02149 | |

DISTRIBUTION (Cont.)

| | Copies |
|---|---|
| Oak Ridge National Lab | |
| Attn: Dr. J. A. Rome | 1 |
| Oak Ridge, TN 37850 | |
| University of California at Los Angeles | |
| Attn: Prof. F. Chen | 1 |
| Dr. A. T. Lin | 1 |
| Dr. J. Dawson | 1 |
| Dr. C. S. Liu | 1 |
| Dr. Edward Ott | 1 |
| Los Angeles, CA 90024 | |
| University of Maryland | |
| Attn: Dr. W. Destlar | 1 |
| Dr. C. S. Liu | 1 |
| Dr. Won Namkung | 1 |
| Dr. E. Ott | 1 |
| Prof. M. Reiser | 1 |
| Dr. Moon-Jhong Rhee | 1 |
| Dr. C. D. Striffler | 1 |
| College Park, MD 20742 | |
| Columbia University | |
| Attn: Prof. P. Diament | 1 |
| Prof. S. Schlesinger | 1 |
| New York, NY 10027 | |
| North Carolina State University | |
| Attn: Prof. W. Doggett | 1 |
| Dr. Jin Joong Kim | 1 |
| P. O. Box 5342 | |
| Raleigh, NC 27650 | |
| Massachusetts Institute of Technology | |
| Attn: Prof. George Bekefi | 1 |
| Dr. K. J. Button | 1 |
| Prof. R. Davidson | 1 |
| Dr. R. Temkin | 1 |
| 77 Massachusetts Avenue | |
| Cambridge, MA 02139 | |

| | Copies |
|---|---|
| University of California | |
| Attn: Dr. Gregory Benford | 1 |
| Dr. A. Fisher | 1 |
| Prof. N. Rostoker | 1 |
| Physics Department | |
| Irvine, CA 92717 | |
| Yale University | |
| Attn: Dr. I. B. Bernstein | 1 |
| Dr. J. L. Hirshfield | 1 |
| Mason Laboratory | |
| 400 Temple Street | |
| New Haven, CT 06520 | |
| Cornell University | |
| Attn: Prof. H. Fleischmann | 1 |
| Prof. D. Hammer | 1 |
| Prof. R. V. Lovelace | 1 |
| Prof. J. Nation | 1 |
| Prof. R. Sudan | 1 |
| Ithaca, NY 14850 | |
| University of Texas at Austin | |
| Attn: Dr. M. N. Rosenbluth | 1 |
| Institute for Fusion Studies | |
| RLM 11.218 | |
| Austin, TX 78712 | |
| Stevens Institute of Technology | |
| Attn: Prof. George Schmidt | 1 |
| Physics Department | |
| Hoboken, NJ 07030 | |
| Dartmouth College | |
| Attn: Dr. John E. Walsh | 1 |
| Department of Physics | |
| Hanover, NH 03755 | |
| Defense Technical Information Center | |
| Cameron Station | |
| Alexandria, VA 22314 | 12 |

MED
8